Cognitive Load Theory

ITTECF reference – Standard 2 – Promote good progress

Split attention demonstration

Time how long it take you to:

Write out all the numbers from 1 to 26 in order, left to right.

---THEN---

Write out all the letters from A to Z in order, left to right.

Make a note of how long that took.

Split attention demonstration

Without looking at your previous work...

Time how long it takes you to:

Write out A1, B2, C3 through to Z26, in order, left to right.

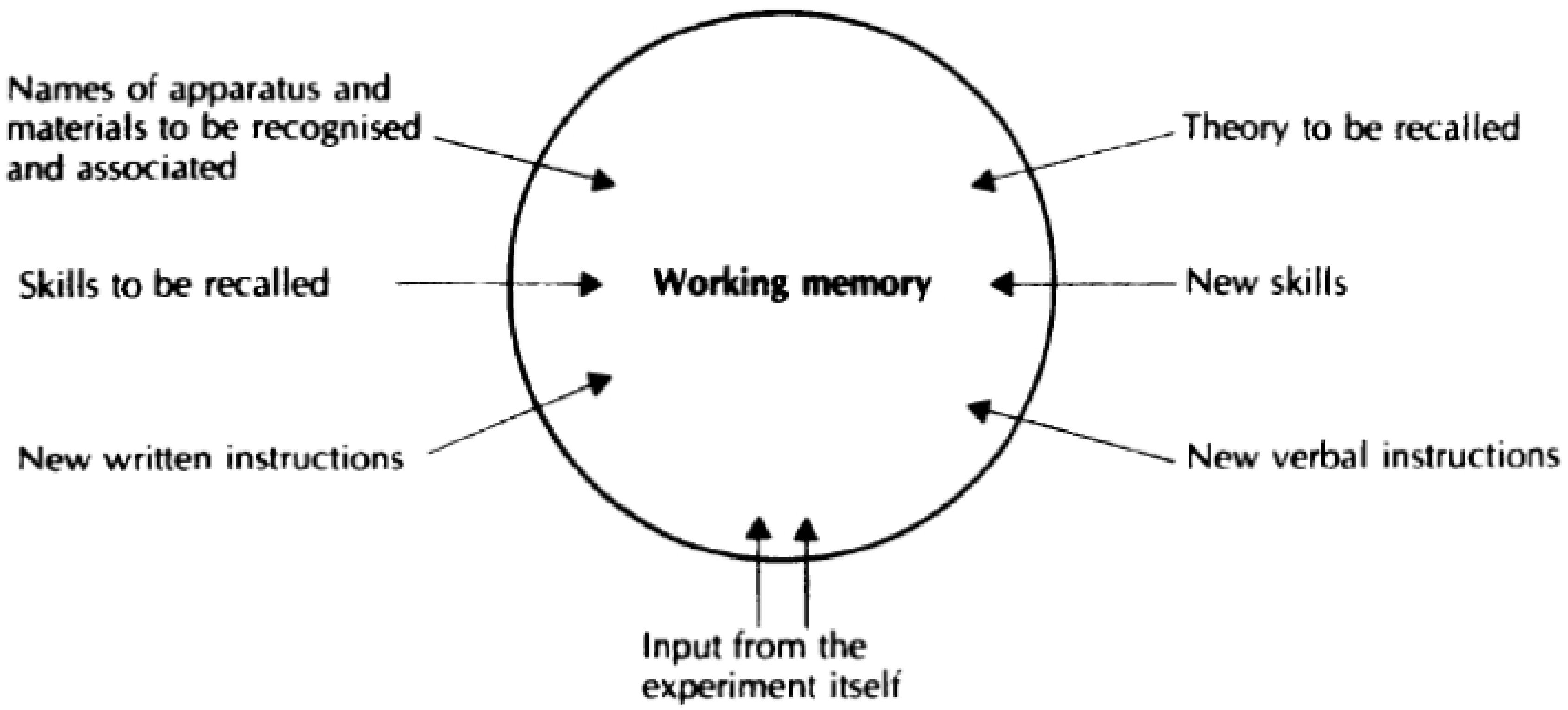
Compare with your previous time.

Practical work and cognitive load

Think about the practical activity you designed yesterday

What are you asking of pupils in terms of cognitive load? (For example, following instructions, applying learning.)

Practical work – a hard ask for students



- Clark, R., Nguyen, F. & Sweller, J. (2006) Efficiency in Learning: Evidence-Based Guidelines to Manage Cognitive Load. John Wiley & Sons.

Cognitive Load Theory (CLT)

- What is happening in the working memory? Three types of load...

Intrinsic
- complexity of concepts
- inter-relatedness of ideas

Extraneous
- complexity of the instructional materials
- external influences

Germane
- building the mental models (schema) about the concepts

Intrinsic load

- Intrinsic load is set by the nature of the content - complex tasks with many interacting elements have a high intrinsic load, while simpler tasks have a lower intrinsic load
- Science practicals often have high intrinsic load, as they involve complex tasks with multiple steps and concepts to process simultaneously.

Extrinsic load

- Extrinsic load is generated by features unrelated to the subject's inherent difficulty - think background noise, distracting displays, overly complex resources, split-attention between multiple sources, or confusing instructions.
- When science practicals have poorly structured instructions, unfamiliar equipment, or confusing setups it can increase extraneous cognitive load, distracting from the main learning objectives.

Germane load

- Germane load is the portion of working memory actively dedicated to constructing, organising, and automating knowledge structures (schemas) from new information.
- Science practicals can promote germane load by encouraging pupils to build and refine scientific schema through active engagement - such as hypothesising, experimenting, and making connections with theory.

- What strategies could you use to manage cognitive load in practical science work?

Strategies to manage cognitive load

Pre-teaching techniques: Teaching the underlying theory and any unfamiliar technical skills beforehand allows pupils to focus on the application rather than wrestling with the basics during the practical.

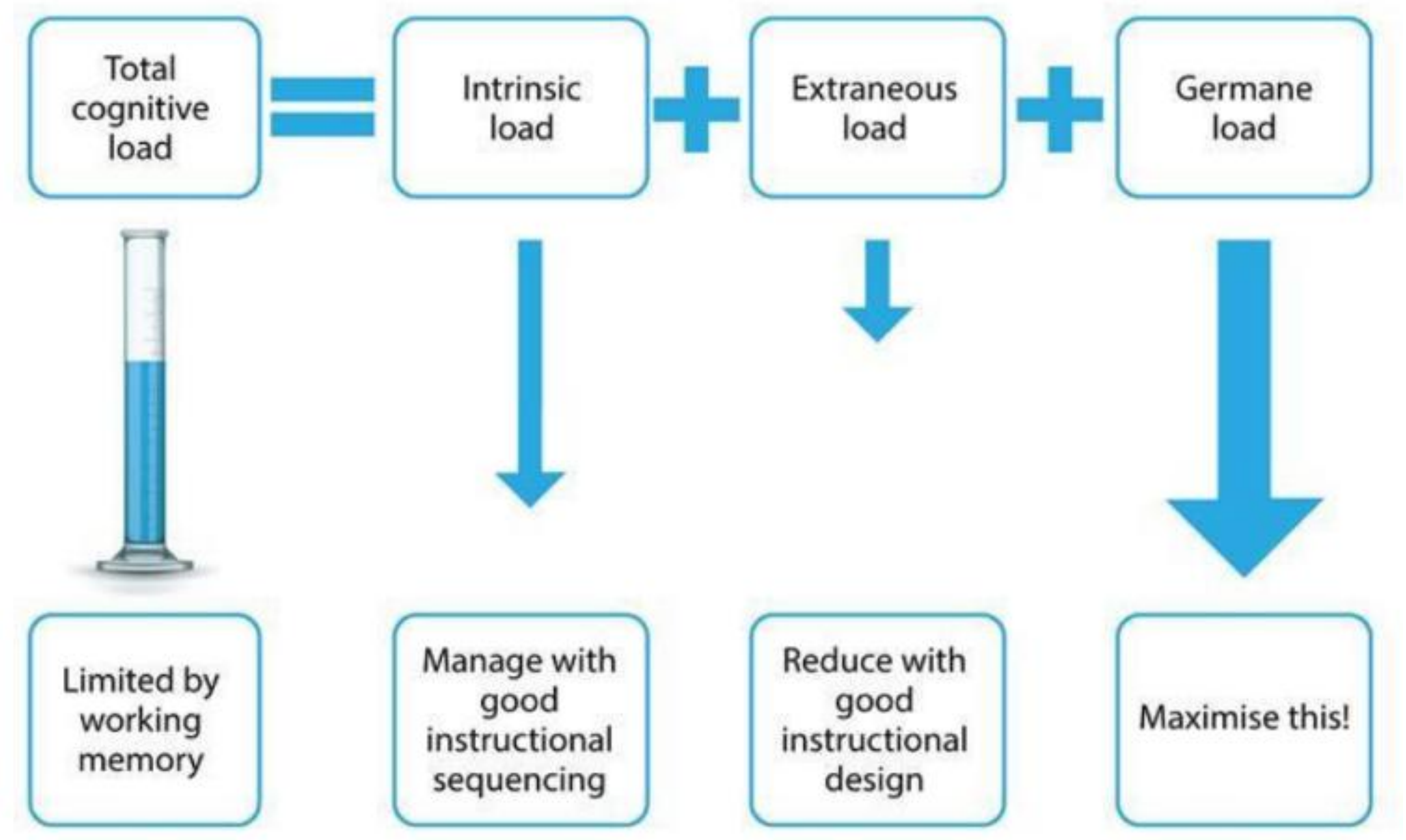
Stepwise instructions: Breaking tasks into clearly defined steps, using visual aids, and minimising unnecessary detail keeps pupils focused and reduces potential overload.

Demonstrations vs. inquiry: Whole-class demonstrations may be more effective for complex techniques, whereas inquiry-based practicals work best when pupils already possess solid background knowledge.

Slow practicals: Encouraging deliberate, stepwise problem-solving - with time for explicit thinking - can transform practicals into powerful learning experiences that optimise cognitive load.

Cognitive Load Theory (CLT)

- Greer, D.L., *et al*, Cognitive theory of multimedia learning..., *Journal of Education,* 2013, 193(2), 41-50
- https://www.researchgate.net/publication/269112838



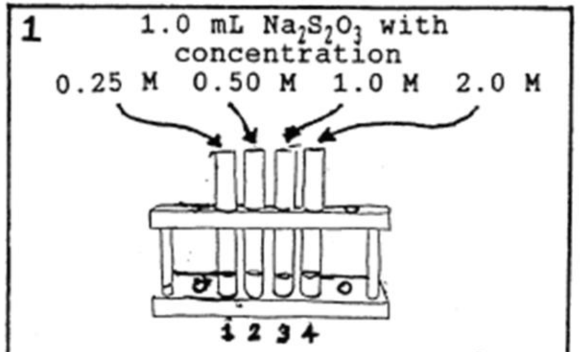
Managing cognitive load in science teaching

- Lesson planning
- Sequencing
- Instructional clarity
- Presentation
- Worked examples
- Modelling
- Scaffolding
- Chunking
- Curriculum design

Integrated Instructions:
Reduce cognitive load
Support independence
Improve accuracy and efficiency
Enhance understanding

1. Obtain four clean, dry test tubes. Pour 1.0 mL samples of sodium thiosulfate solution ($Na_2S_2O_3$) into the tubes as follows:

Tube 1	0.25 M	$Na_2S_2O_3$
Tube 2	0.50 M	$Na_2S_2O_3$
Tube 3	1.0 M	$Na_2S_2O_3$
Tube 4	2.0 M	$Na_2S_2O_3$



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Deschri *et al* (1997), J Res Sci Teach, 34(9), 891-904: Effect of a Laboratory Manual Design Incorporating Visual Information-Processing Aids on Student Learning and Attitudes

Making integrated instructions

https://eic.rsc.org/feature/improving-practical-work-with-integrated-instructions/3009798.article

FEATURE

Improving practical work with integrated instructions

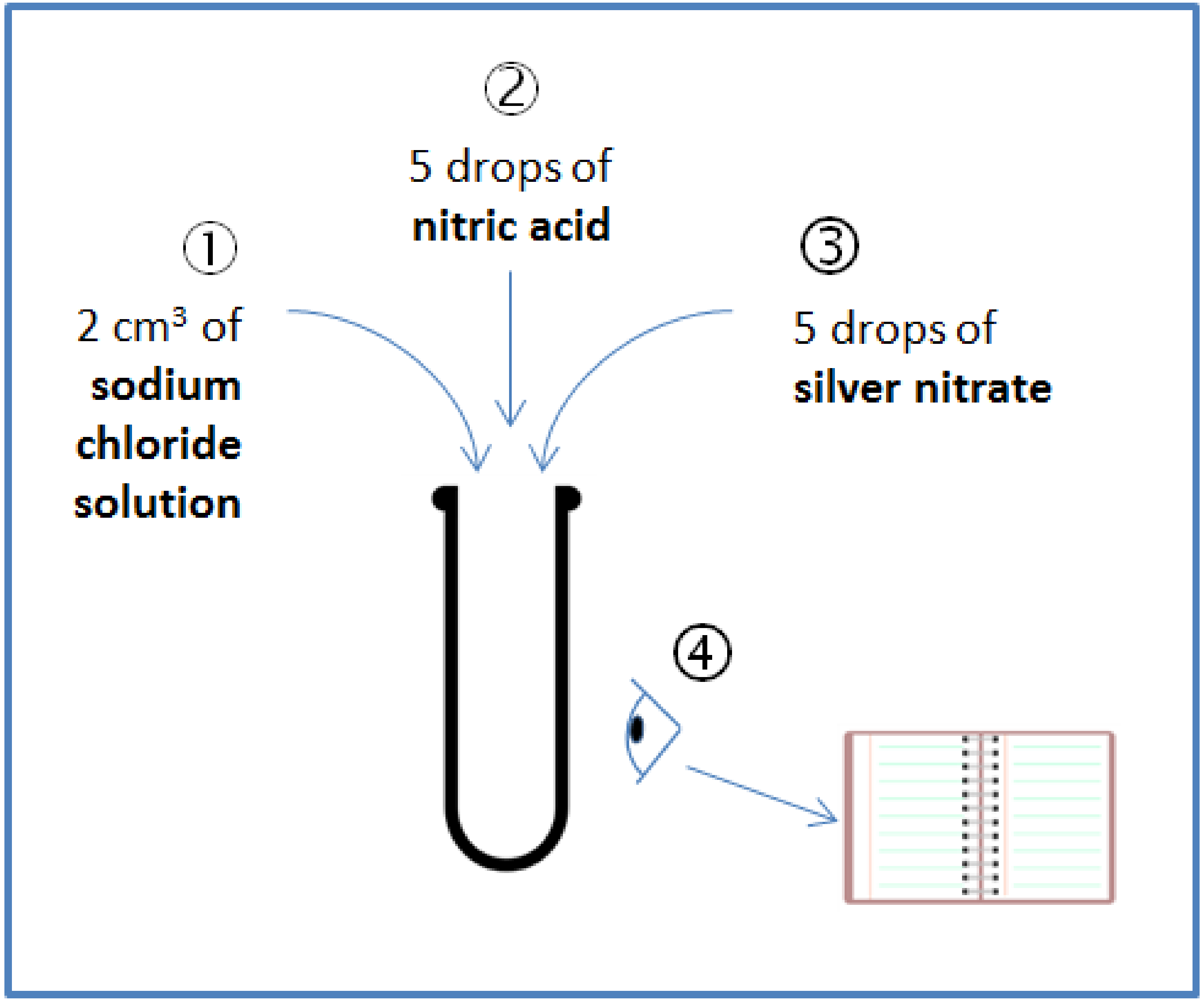
28 NOVEMBER 2018

Do your students struggle to follow written instructions?

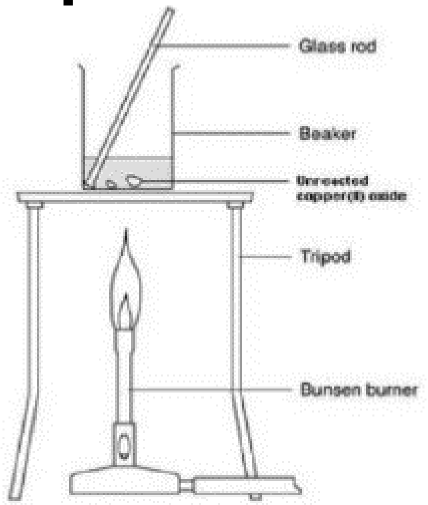
educationinchemistry

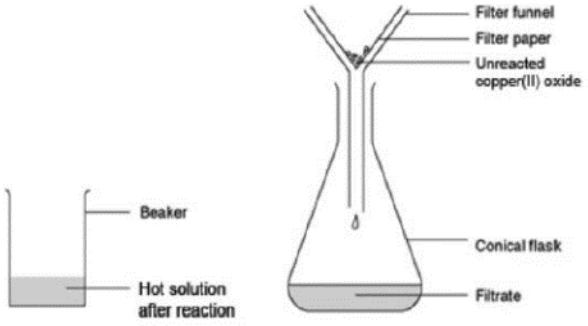
Integrated Instructions

1. Add 2 cm^3 of 0.2 M sodium chloride solution to a test tube.
2. Add 5 drops of 0.5 M nitric acid to the same test tube.
3. Add 5 drops of 0.1 M silver nitrate solution to the same test tube.
4. Make and record your observations.



Split attention in practical work



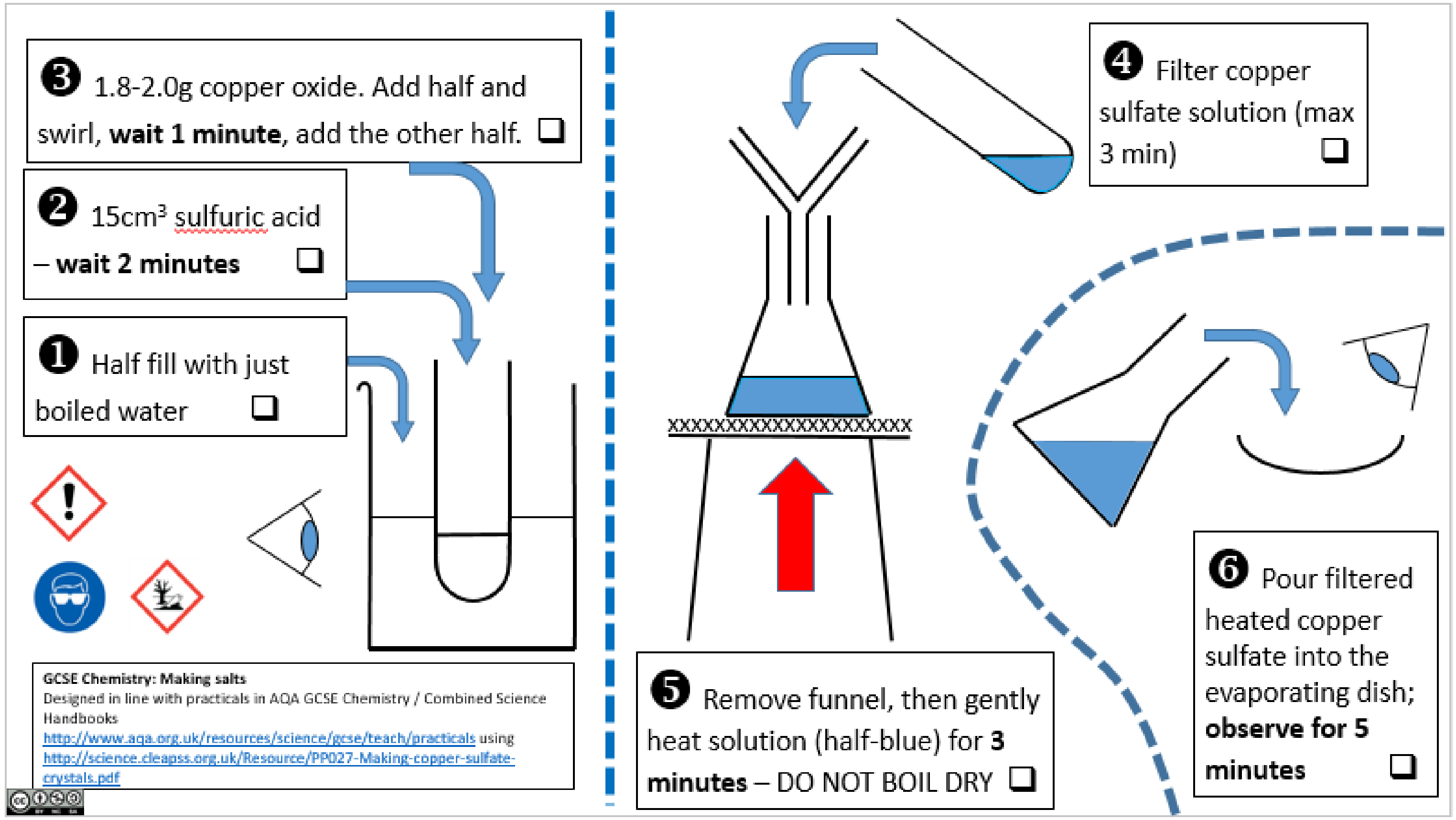


a Add 20 cm3 of the 0.5 M sulfuric acid to the 100 cm3 beaker. Heat carefully on the tripod with a gentle blue flame until nearly boiling.
b When the acid is hot enough (just before it starts to boil), use a spatula to add small portions of copper(II) oxide to the beaker. Stir the mixture gently for up to half a minute after each addition.
c When all the copper(II) oxide has been added, continue to heat gently for 1 to 2 minutes to ensure reaction is complete. Then turn out the Bunsen burner. It may be wise to check (using pH or litmus paper) that no acid remains. If the acid has not been hot enough, excess acid can co-exist with copper oxide.
d Allow the beaker to cool slightly while you set up Stage 2.
Stage 2
e Place the filter funnel in the neck of the conical flask.
f Fold the filter paper to fit the filter funnel, and put it in the funnel.
g Make sure the beaker is cool enough to hold at the top. The contents should still be hot.
h Gently swirl the contents to mix, and then pour into the filter paper in the funnel. Allow to filter through.
i A clear blue solution should collect in the flask. If the solution is not clear, and black powder remains in it, you will need to repeat the filtration.
Stage 3 (optional)
j Rinse the beaker, and pour the clear blue solution back into it. Label the beaker with your name(s). Leave the beaker in a warm place, where it won't be disturbed, for a week or so. This will enable most of the water to evaporate. would fill with toxic fumes.
k Before all the water has evaporated, you should find some crystals forming on the bottom of the beaker. Filter the solution. Collect the crystals from the filter paper onto a paper towel.

http://www.rsc.org/learn-chemistry/resource/res00001917/reacting-copper-ii-oxide-with-sulfuric-acid?cmpid=CMP00006703

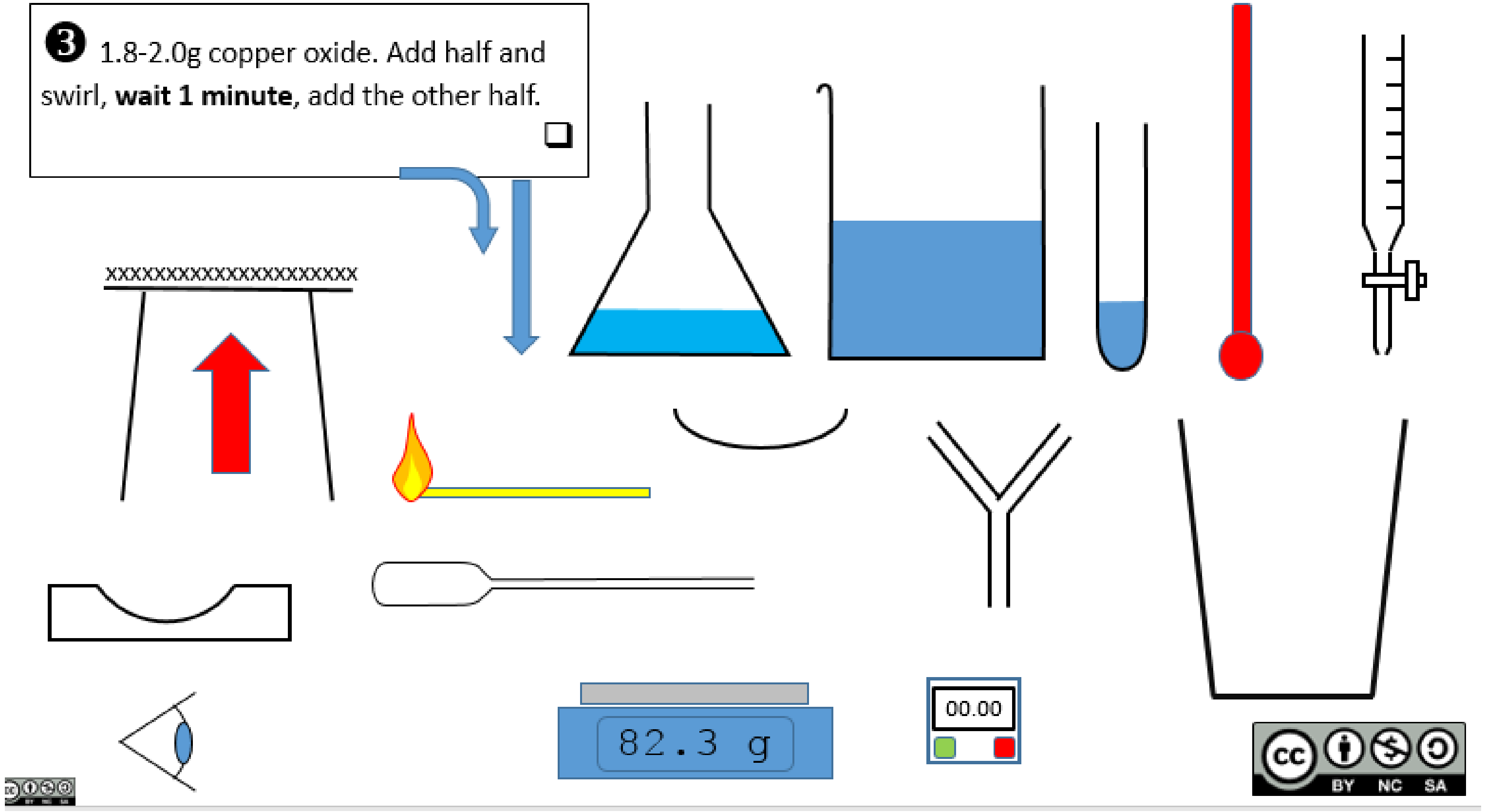
Cook, M.P., 2006. Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles. *Science education*, *90*(6), pp.1073-1091.

Integrated-instructions in practical work



Making integrated instructions

https://dave2004b.wordpress.com/2018/02/25/integrated-instructions-templates/



Year 9: Traditional vs Integrated

PRACTICAL : Catalysis of the reaction between zinc and sulfuric acid

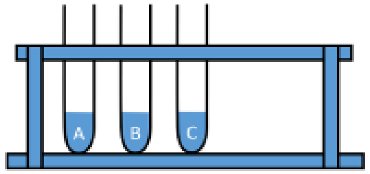
Purpose: To compare the rate of reaction of zinc with sulfuric acid in the absence and presence of catalysts.

Safety: Wear eye protection; tie back long hair

Equipment:

- test tubes (3)
- test tube rack
- measuring cylinder (10cm^3)
- dropping pipette
- spatula
- granulated zinc (a few pieces)
- copper turnings (a few pieces)
- sulfuric acid, 1M (IRRITANT) (15cm^3)
- copper(II) sulfuate(VI) solution, 0.5M (a few cm^3)
- marker pen

Diagram



Method

1. Label three test tubes A, B, C
2. Add a few pieces of granulated zinc into each of the test tubes – try to have the same amount in each tube.
3. Add 5cm^3 of sulfuric acid to test tube A using a measuring cylinder.
4. Observe and estimate the rate (speed) of production of gas bubbles – note this in your table.
5. Add a few copper turnings to test tube B using a spatula, making sure they are in contact with the zinc.
6. Add 5cm^3 of sulfuric acid to test tube B using a measuring cylinder.
7. Observe and estimate the rate (speed) of production of gas bubbles – note this in your table.
8. Add 5cm^3 of sulfuric acid to test tube C using a measuring cylinder.
9. Add about 1cm^3 of copper sulfate solution to test tube C using a dropping pipette.
10. Observe and estimate the rate (speed) of production of gas bubbles – note this in your table.
11. Observe and note what happens to the colour of the solution and the surface of the zinc in test tube C over 1-2 minutes.

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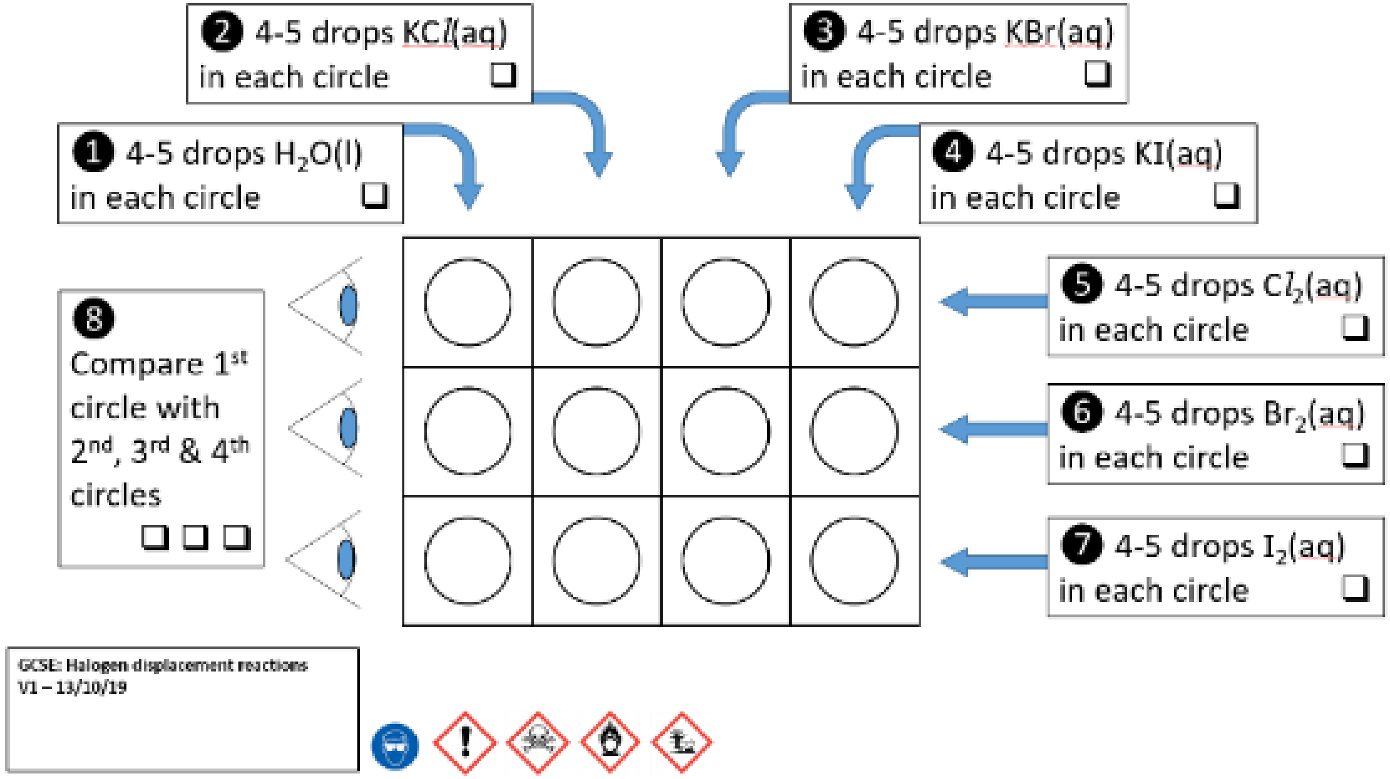


Year 12: Traditional vs Integrated

PRACTICAL : Finding the formula of magnesium oxide

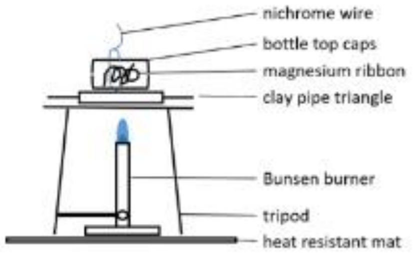
Purpose: To experimentally determine the empirical formula of magnesium oxide

Safety: Wear eye protection; tie back long hair

Equipment:

- Bottle tops (2)
- Nichrome wire (15cm)
- Magnesium ribbon (10-12cm)
- Heat resistant map
- Bunsen burner
- Tripod
- Clay pipe triangle (small)
- Pencil

Diagram



Method

1. Measure the mass of 2 bottle tops and 15cm nichrome wire. Record this mass as **M1**.
2. Wrap a 10-12cm piece of magnesium ribbon round a pencil and place the ribbon in one of the bottle tops.
3. Place the second bottle top on top of the first, serrated edges together.
4. Wrap the nichrome wire around the bottle tops to keep them together.
5. Measure the mass of 2 bottle tops, nichrome wire and magnesium ribbon. Record this mass as **M2**.
6. Set up the Bunsen burner and tripod on a heat resistant mat. Place the clay pipe triangle on the tripod.
7. Place the bottle-top package securely on top of the clay-pipe triangle.
8. Heat the bottle tops with a strong, non-luminous flame. When the magnesium ignites, you might be able to see the bright glow. Keep heating for 10 minutes, or until you can no longer see a bright light between the bottle tops.
9. Switch off the Bunsen burner and allow the bottle tops to cool for 5 minutes.
10. Measure the mass of the 2 bottle tops, nichrome wire and magnesium oxide. Record this mass as **M3**.
11. Calculate the mass of magnesium used as **M2 – M1**, and magnesium oxide as **M3 – M1**.
12. Use the calibration graph below to deduce the empirical formula of magnesium oxide.

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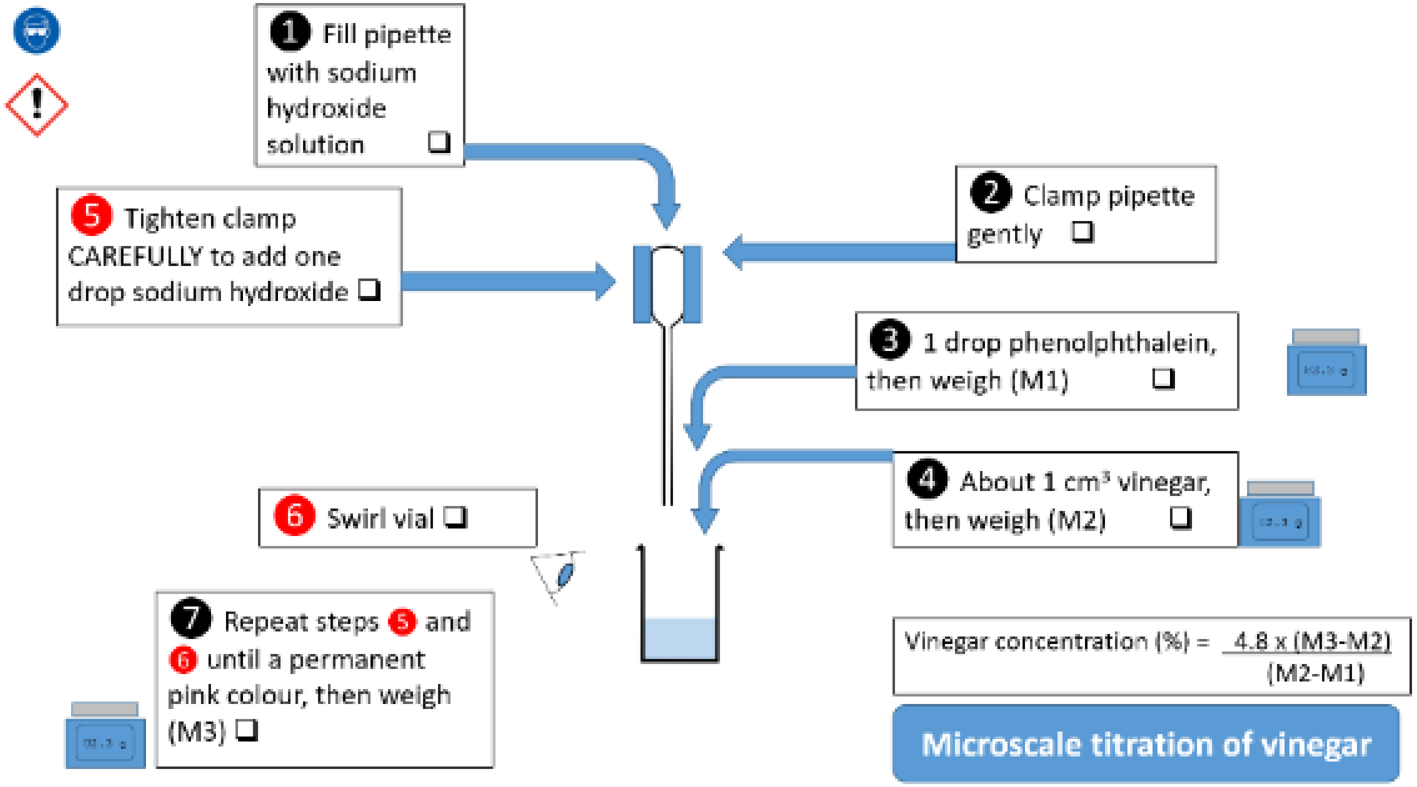
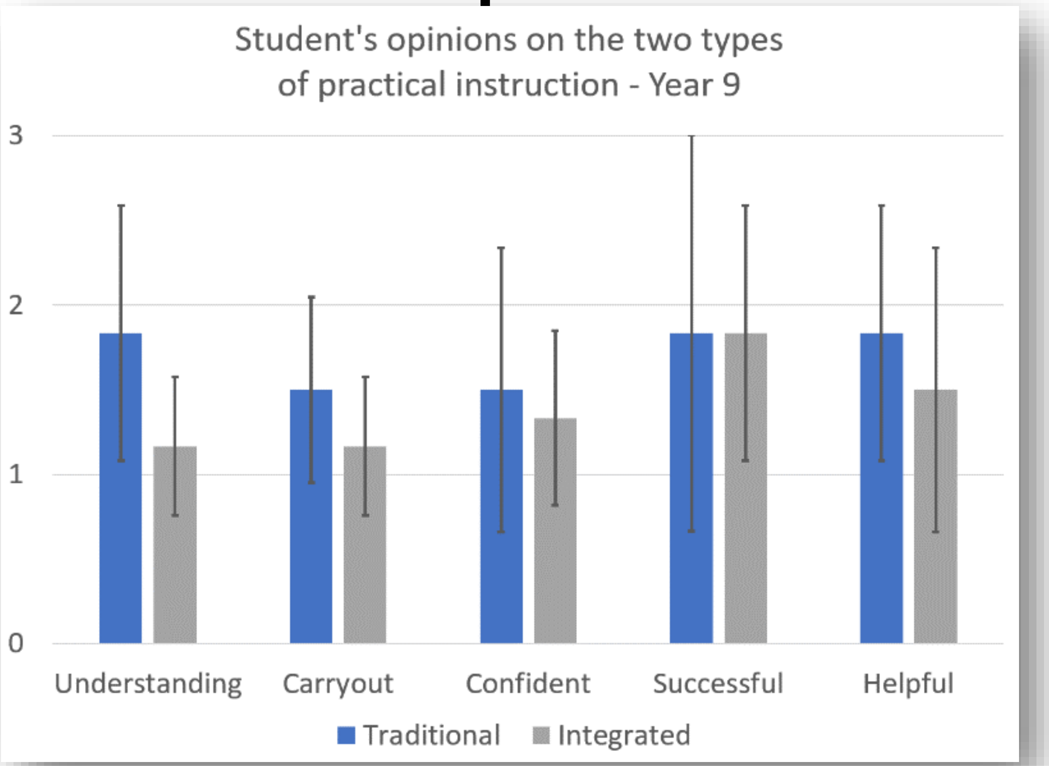
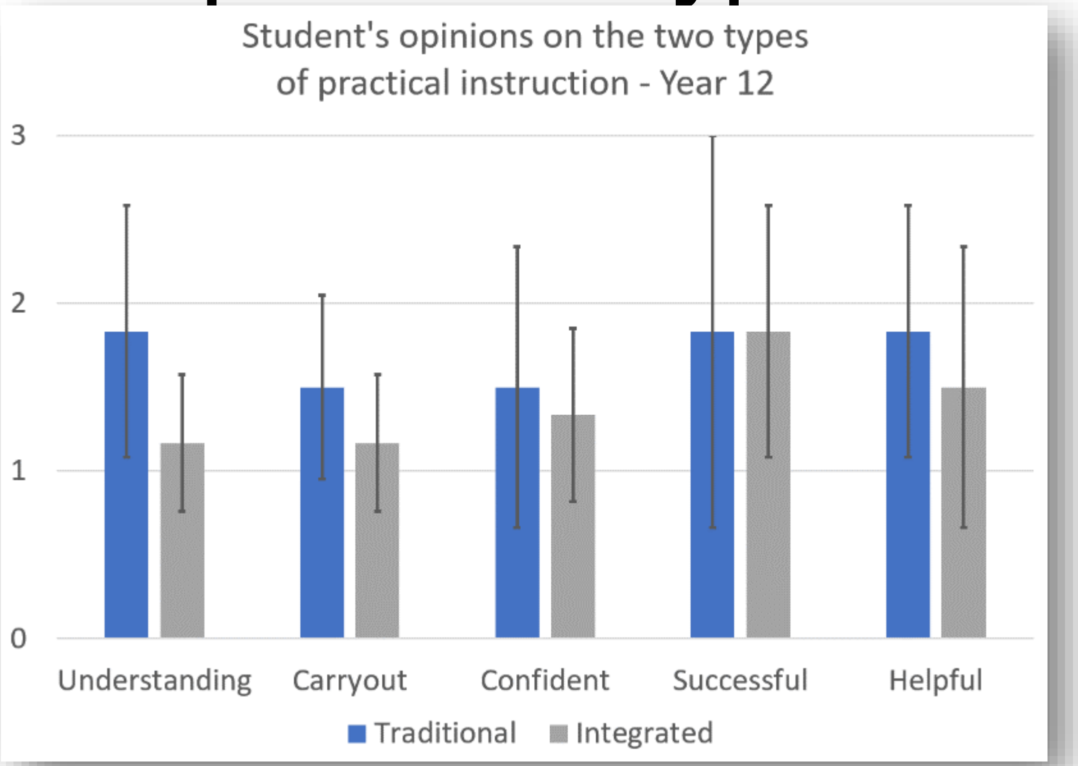


Student opinions of different practical types

lower is better





Understanding – How easy/hard did you find it to understand the practical instructions?
Carryout – How easy/hard did you find it to carry out the practical work?
Confident – How confident did you feel during the practical work?
Successful – How successful did you feel at the end of the practical?
Helpful – How helpful was the practical in your learning?

Planning support

- Can you create a set of integrated instructions for your chosen practical activity?
- Share these with another group.
- Peer assess:
  - Would you be able to follow these instructions without asking any questions?

References

- Clark, R., Nguyen, F. & Sweller, J. (2006) Efficiency in Learning: Evidence-Based Guidelines to Manage Cognitive Load. John Wiley & Sons.
- Cook, M.P., 2006. Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles. *Science education*, *90*(6), pp.1073-1091.
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- Paterson, D.J., 2019. Design and evaluation of integrated instructions in secondary-level chemistry practical work. *Journal of Chemical Education*, *96*(11), pp.2510-2517. (Not available for full text view)
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Sweller, J., Van Merrienboer, J.J. and Paas, F.G., 1998. Cognitive architecture and instructional design. *Educational psychology review*, *10*(3), pp.251-296.

Exemplar metacognitive strategies which can reduce cognitive load

Technique	Description
1. Elaborative interrogation	Generating an explanation for why an explicitly stated fact or concept is true
2. Self-explanation	Explaining how new information is related to known information, or explaining steps taken during problem solving
3. Summarization	Writing summaries (of various lengths) of to-be-learned texts
4. Highlighting/underlining	Marking potentially important portions of to-be-learned materials while reading
5. Keyword mnemonic	Using keywords and mental imagery to associate verbal materials
6. Imagery for text	Attempting to form mental images of text materials while reading or listening
7. Rereading	Restudying text material again after an initial reading
8. Practice testing	Self-testing or taking practice tests over to-be-learned material
9. Distributed practice	Implementing a schedule of practice that spreads out study activities over time
10. Interleaved practice	Implementing a schedule of practice that mixes different kinds of problems, or a schedule of study that mixes different kinds of material, within a single study session

Note. See text for a detailed description of each learning technique and relevant examples of their use.

Donker, A. S., de Boer, H., Kostons, D., Dignath van Ewijk, C. C., & van der Werf, M. P. C. (2014) Effectiveness of learning strategy instruction on academic performance: A meta-analysis. *Educational Research Review*, *11*, 1–26. https://doi.org/10.1016/j.edurev.2013.11.002. (Table taken from p6)

How do you reduce extraneous load

technique	Description	Impact
Worked example	Replaces conventional problems and crutches with worked examples.	Reduces extraneous load by exemplifying key steps to problems.
Completion effect (faded examples)	Replace conventional problems with worked examples where certain steps are missing	Reduces extraneous load by gradually giving different parts of the problem allowing time to embed each step
Split attention effect		
Modality effect	Remove excess text from slides use visual cues with narration to explain concepts	Reduces extraneous load as the multimodal presentation visual and auditory processors
Goal free effect	Replace conventional problems with goal free problems which provide students with non specific goal	Reduces extraneous load caused by relating a problem to a specific goal
Redundancy effect	Replace multiple sources of information and distractors	Reduces extraneous load caused by unnecessarily processing redundant information

Journal of Chemical Education article

Design and Evaluation of Integrated Instructions in Secondary-Level Chemistry Practical Work

David J. Paterson*

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SUBJECTS: Teaching and learning methods, Anions,